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Dust explosion venting of small vessels and flameless venting

P. Holbrow *

Health and Safety Laboratory, Harpur Hill, Buxton SK17 9JN, UK

ABSTRACT

Dust explosion venting is an established method of protecting against damaging explosion over-pressures, and guidance is available for many industrial situations. However, there is a need to: (a) establish the venting requirements of small vessels and whether current guidance and predictions in BS EN 14491:2006 need revising, and (b) improve understanding of the potential and limitations of flameless venting. This paper describes initial results from an ongoing programme of research.

Small vessel tests are carried out using cornflour and wood dust on: a commercial sieve unit, a commercial cyclone, and a 0.5 m^3 test vessel with explosion-relief openings without vent covers. Initial 0.5 m^3 vessel tests give reduced explosion pressures that are lower than those predicted. This is because the predicted pressures are based on openings with vent covers. The reduced explosion pressures measured in the sieve unit and the cyclone are also less than predicted: the reasons are discussed.

Flameless vesting tests are carried out using cornflour and wheat flour on a commercial flame arrestor unit. Initial tests demonstrate benefits, particularly a high level of flame extinguishment, but a problem of reduced venting efficiency compared to conventional venting.

These initial results indicate that further research is needed.

Keywords: Dust explosion; Venting; Flameless venting

1. Introduction

Dust explosion venting is a well-established method of protecting against damaging explosion overpressures. The principle is well-known; in the early stages of an explosion, weak panels in the walls of the vessel, or an explosion venting device, open at a low overpressure. Much of the explosion is then dissipated outside the vessel, and the maximum pressure inside the vessel is reduced (P_{red}).

There is already guidance available for the application of explosion venting in many industrial situations. However, industrial and technological developments have led to the need for further research into: the explosion venting requirements of small vessels, and the potential limitations of flameless venting. This paper describes the initial results from an ongoing programme of research.

1.1. *Explosion venting requirements of small vessels (<0.5 m^3)*

Venting has been claimed to be unnecessary in some cases. For example, guidance published by the Solids Handling and Processing Association (SHAPA, 2011) states that for small vessels such as a dust collector with inlet and outlet openings, enclosing a volume typically about 0.5 m^3 or less that handle material of dust specific explosibility characteristic (K_{St}) up to 200 bar m s^{-1} (St1), it may not be necessary to provide explosion relief.

The aim of this programme of research is:

(a) To establish the venting requirements, if any, of small process vessels. In particular this will consider the conditions and dusts for which it has been claimed that venting is not required.

* Tel.: +44 0 1298 218144.
E-mail address: paul.holbrow@hsl.gov.uk

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(b) To determine whether the current guidance on venting of small vessels needs revision.

This paper describes initial results from experimental tests in small vessels and, in the absence of a design guide for small vessels, compares the overpressures with those predicted using the vent sizing method described in BS EN 14491:2006. The standard specifies the basic requirements of design for the selection of a dust explosion venting protective system. For the venting of single enclosures the following equation is used:

$$A_v = V^{0.753} 3.264 \times 10^{-5} \cdot P_{max} \cdot K_{st} P_{red}^{-0.569}$$
$$+ 0.27(P_{stat} - 0.1)P_{red}^{-0.5} \times (1 + [-4.305 \log P_{red}$$
$$+0.758] \log(L/D))$$

where

A_v is the vent area (m^2)	
V is the vessel volume (m^3)	$0.1\,m^3 \le V \le 10{,}000\,m^3$
K_{St} is the dust explosibility characteristic ($bar\,m\,s^{-1}$)	
P_{max} is the maximum explosion pressure (bar)	$5\,bar \le P_{max} \le 10\,bar$ for K_{St} values of $10\,bar\,m\,s^{-1} \le K_{St} \le 300\,bar\,m\,s^{-1}$ $5\,bar \le P_{max} \le 12\,bar$ for K_{St} values of $300\,bar\,m\,s^{-1} \le K_{St} \le 800\,bar\,m\,s^{-1}$
P_{red} is the reduced explosion pressure (bar)	$P_{stat} \le P_{red} \le 2\,bar$
Recommended that P_{red} shall be at least 0.12 bar	
P_{stat} is the opening pressure of the vent (bar)	$0.1\,bar \le P_{stat} \le 1\,bar$; for $P_{stat} < 0.1\,bar$, use P_{stat} 0.1 bar
L/D is the length-to-diameter ratio	$1 \le L/D \le 20$

The equation is valid for vents fitted with vent covers having $0.1\,bar \le P_{stat} \le 1\,bar$. However, the experimental test results are likely to be lower than the predictions because (a) the small test vessels are not fitted with vent covers, and (b) the experimental tests do not always produce a homogeneous dust cloud and spherical flame front due to the physical shape of the test vessels. For the purpose of the comparison a P_{stat} of 0.1 bar was assumed for the predicted overpressures.

1.2. *Potential limitations of flameless venting devices*

Industrial flameless venting devices are designed to extinguish the flame and prevent the discharge of large quantities of dust from the vented vessel into the surroundings. They consist of a flame-arrestor element, closed at one end and open at the other, that quenches the flame as the vent operates. The device is bolted to the clean side of the explosion vent on the vessel. It is reported by Snoeys (2011) that the dust will be retained in the cylinder and, because of heat absorption, the flame from the explosion will be extinguished as it travels through the flame arrestor section. Advantages of flameless venting are claimed to be flame extinguishment, dust retention, potentially eliminating the need for explosion vent ducts to outside the workroom. Venting efficiencies of 84–100% have been reported by Going and Chatrathi (2003) and 70–90% by Stevenson (1998).

The aim of this programme of research is to generate greater understanding of the potential and the limitations of flameless venting. This paper discusses initial experimental results on the performance of a flameless venting device installed with a $2\,m^3$ vessel.

2. Test dusts used

The test dusts used in the small vented vessel tests were cornflour and wood dust. The test dusts used in the flameless venting tests additionally included wheat flour. Wood dust was selected as it represents a different morphology to cornflour.

Details of the test dusts are presented in Table 1 where P_{max}, the maximum explosion pressure, and K_{St}, the dust specific explosibility characteristic, are as defined in the European standards: BS EN 14034-1 (2004) and BS EN 14034-2 (2006). These characteristics are measured in a standard test at the optimum dust concentration and are obtained by testing the dust over a wide range of dust concentrations. The $(dP/dt)_{max}$ is used to calculate the K_{St} ($bar\,m\,s^{-1}$) using the following equation:

$$K_{St} = \left(\frac{dP}{dt}\right)_{max} V^{1/3}$$

where $(dP/dt)_{max}$ is the peak maximum rate of pressure rise ($bar\,s^{-1}$) and V is the total internal volume of the test vessel (m^3).

3. Explosion venting of small vessels

3.1. *Method*

Measurements of P_{red} were carried out using three test vessels and compared with those predicted by BS EN 14491:2006. The vessels were: a $0.5\,m^3$ vented test vessel, a commercial sieve unit and a commercial cyclone. Details are as follows.

3.1.1. *$0.5\,m^3$ test vessel method*

A vented test vessel with an internal volume of approximately $0.5\,m^3$ was specially constructed for this research project. It has a diameter of 0.914 m and a length of 0.8 m, with a front face fitted with a 0.4 m diameter vent opening capable of accepting smaller vent openings (Fig. 1). Two flanged connections are located on the side of the vessel each with nominal bore of 97 mm diameter. The total vent area was varied by closing off the various openings.

Ports were located on the side of the vessel to accept instrumentation and ignition equipment. The dust cloud is produced by injection of a pre-weighed mass of dust into the vessel from an external pressurised dust injection system.

The pressure–time history within the test vessel is measured using transducers positioned at the wall of the vessel. The ignition source was located at the vessel centre-line and comprised an electric fuse head inside a polythene pouch containing blackpowder.

Table 1 – Test dusts.

Dust	HSL reference	K_{St} (bar m s^{-1})	P_{max} (bar g)	Moisture content (%w/w)	Particle size distribution
Corn flour	EC/084/09	147	7.9	13.5	100% < 63 μm
Wheat flour	EC/107/09	138	8.0	11	100% < 180 μm 65.9% < 106 μm 10% < 63 μm
Wood dust	EC/074/09	113	10.4	7.6	62.5% < 500 μm 49.2% < 250 μm 44.1% < 180 μm 31.4% < 106 μm 15.9% < 63 μm

Fig. 1 – Test vessel.

Tests in the 0.5 m^3 test vessel were done without vent covers and with a range of vent areas to simulate small process vessels having open connections. Tests were done to establish the test conditions including the optimum ignition delay for maximum pressure rise; this was found to be 250 ms.

3.1.2. Sieve unit method

A commercial sieve unit was obtained specifically for the test programme (Fig. 2). The vibratory motion eliminates oversize material from the feed via a sieve screen with an appropriate sized mesh. The upper and lower chambers of the sieve unit are separated by the sieve screen. Internal volumes are approximately 0.1 m^3 above and 0.1 m^3 below the sieve screen. The test programme used 140 μm, 250 μm and 500 μm mesh screens.

Material is fed into the sieve via the 250 mm diameter inlet in the upper chamber. Oversize material travels across the screen and is discharged through a 150 mm outlet in the upper chamber, and the undersize material is discharged through a 250 mm diameter outlet in the lower chamber. This lower chamber is where a dust cloud is likely to be located and therefore the igniter is positioned centrally in this chamber. The sieve unit is powered by an external vibratory motor and is supported on four rubber mountings, which secure the unit to its steel support frame. Two pressure transducers were located on the sieve, one at the upper wall and one at the lower chamber wall.

3.1.3. Cyclone method

A small medium-efficiency commercial cyclone (Fig. 3) was tested. It is constructed from 2 mm thick carbon steel with dimensions as shown in the schematic diagram in Fig. 4. The cyclone had a vortex finder that extended into the cyclone for a depth of 500 mm, without internal bracing. This type of cyclone is typically used as a pre-separator before a conventional bag filter. The manufacturer states that the separation efficiency for wood dusts can exceed 90%, but is lower for finer dusts.

The dust cloud is produced by pneumatically conveying the test material into the cyclone from an external fan/dust feed system and a 100 mm diameter flexible hose. Additionally, a series of tests were done with the dust cloud formed by dispersing the dust from an external dust injection system to explore whether more severe conditions could be achieved.

The dust is ignited using a strong ignition source located within the cyclone. The pressure–time history is recorded using a pair of pressure transducers mounted at the cyclone wall.

The dust feed rate for each dust was obtained by calibration in advance of the tests; the rate was varied by adjusting the outlet aperture in the hopper. After the dust was observed flowing from the cyclone outlet, the igniter was fired.

Fig. 2 – Sieve unit.

Fig. 3 – Cyclone.

3.2. *Results for small vessel venting*

3.2.1. *0.5 m³ vessel results*

The measured and predicted reduced explosion pressures are plotted against vent area and are shown in Figs. 5 and 6 for corn flour and wood dust respectively. A P_{stat} value of 0.1 bar

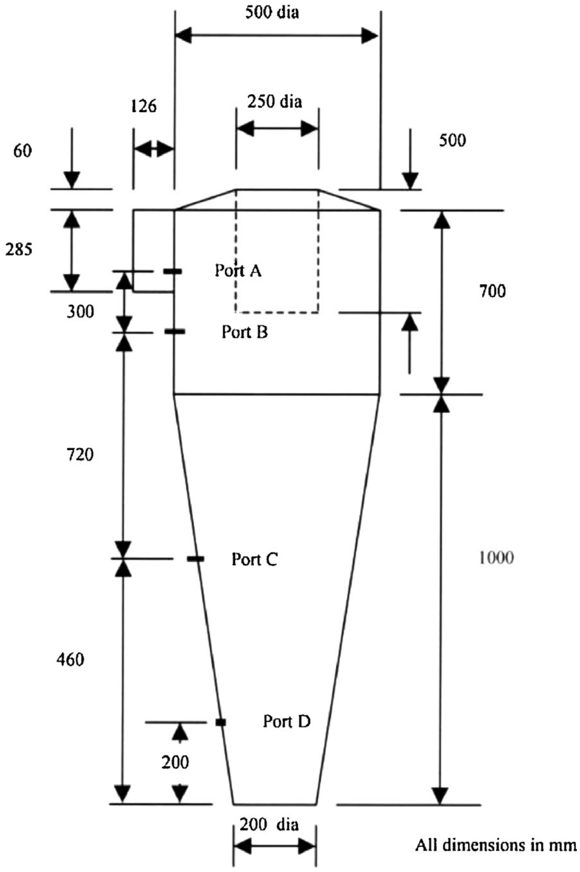

Fig. 4 – Cyclone.

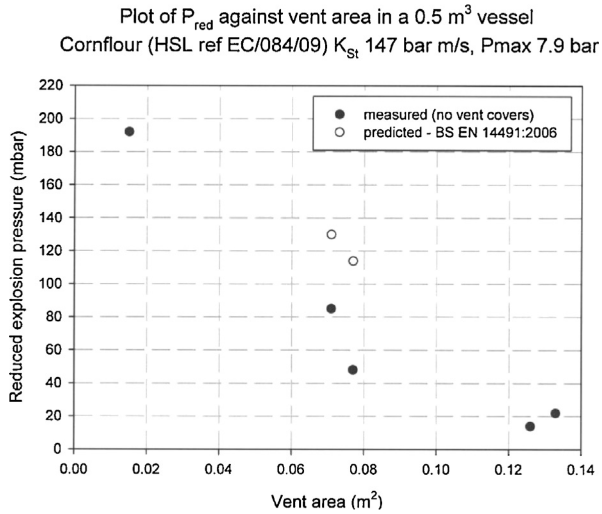

Fig. 5 – Vent area vs. P_{red} in the 0.5 m³ vessel for cornflour.

has been used in the predictive equation. It should be noted that for normal vent sizing the predictive equation should not normally be used for estimating P_{red} values below the recommended P_{red} of 0.12 bar and for vent openings that are not fitted with a vent covers. However, in the absence of other predictive techniques the equation serves to illustrate the upper limit of pressures that could be generated.

A vented explosion test in the 0.5 m³ vessel is shown in Fig. 7.

3.2.2. *Sieve unit results*

The peak measured P_{red} values and those predicted by the standard venting equation (BS EN 14491:2006) are given in Table 2 for tests with the smallest outlet (oversize outlet) open.

Fig. 8 shows an example sieve test.

3.2.3. *Cyclone results*

The peak measured P_{red} values and the predicted P_{red} values are presented in Table 3.

Pneumatically conveyed dusts were tested over a range of dust concentrations and igniter positions. The optimum igniter position for the highest P_{red} values was the lower portion of the cyclone cone.

Fig. 9 shows a pressure–time trace from the most severe pneumatic test (Test 60) where corn flour was ignited in the

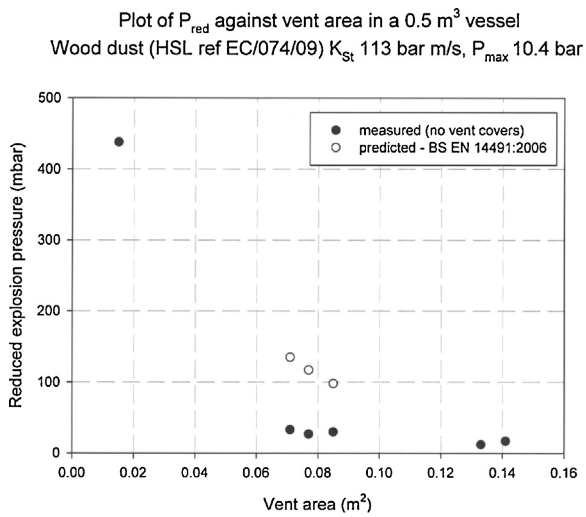

Fig. 6 – Vent area vs. P_{red} in the 0.5 m³ vessel for wood dust.

Table 2 – Peak measured and predicted P_{red} in the sieve unit.

Dust	Peak measured P_{red} (mbar)	Predicted P_{red} (BS EN 14491:2006) (mbar)
Corn flour	196	350
Wood dust	175	350

Table 3 – Peak measured and predicted P_{red} in the cyclone.

Dust	Peak measured P_{red} (mbar) Pneumatic tests	Peak measured P_{red} (mbar) Injected tests	Predicted P_{red} (mbar) (BS EN 14491:2006) (mbar)
Corn flour	60	24	380
Wood dust	66	34	380

Fig. 7 – Test in the 0.5 m^3 vessel.

bottom of the cone. Fig. 10 is a frame from the video film of this test and demonstrates the vented combustion products and dust from the top outlet of the cyclone.

3.3. *Discussion*

3.3.1. *0.5 m^3 vessel discussion*

It can be seen from Figs. 5 and 6 that the measured P_{red} values were lower than those predicted by the standard venting equation in BS EN 14491:2006. For example, with a vent area of 0.07 m^2, BS EN 14491:2006 predicts a P_{red} of 132 mbar and 134 mbar for cornflour and wood dust respectively, whereas the experimental data indicates that the actual pressures were lower with values of approximately 80 mbar for cornflour and 50 mbar for wood dust.

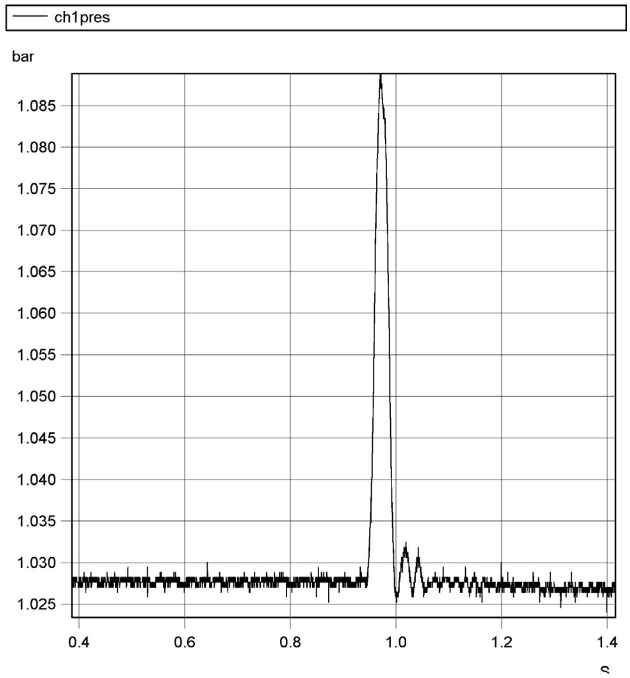

Fig. 9 – Pressure (bar)–time (s) trace for the most severe cyclone test with cornflour for pneumatic injection.

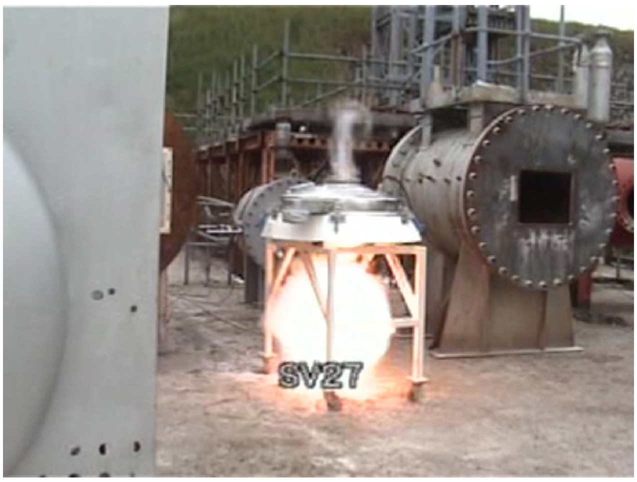

Fig. 8 – Sieve test.

Fig. 10 – The most severe pneumatic cyclone test (corresponding to the trace in Fig. 9).

Reducing the size of the open connection in the vessel increases the P_{red}. For example, a 0.02 m^2 vent opening, results in a P_{red} of 180 mbar for corn flour and 350 mbar for wood dust. Hence the vessel must to be designed to withstand the higher explosion pressure.

The predicted P_{red} values are higher than the measures test values mainly because BS EN 14491:2006 is based on the situation where the vent openings are fitted with vent covers. The presence of a vent cover increases the P_{red} due to the initial confinement before the cover opens at its designed opening pressure. This assumes that the open connections are able to vent freely without restriction, i.e. if a long length of pipe is attached to the opening, its effect will be to increase the backpressure. This is clearly demonstrated by the vent duct guidance published by the Institution of Chemical Engineers (Barton, 2002). A further possible reason for the higher predicted values is that the equation given in EN 14491 is based on an envelope of experimental results, and may result in conservative estimations for the 0.5 m^3 vessel.

Decreasing the effective vent area further will increase the P_{red} significantly with the potential for pressures up to the maximum explosion pressure of the dust, typically 7–10 bar.

The well-dispersed dust cloud and high turbulence conditions produced using the 0.5 m^3 test vessel means that the P_{red} data obtained from the tests is likely to be as severe or greater than similar small vessels found in industry.

3.3.2. *Sieve unit discussion*

It can be seen from Table 2 that the maximum measured values of P_{red} in the sieve unit are lower than those predicted. The difference in the measured and the predicted P_{red} can be accounted for by the fact that the sieve unit is far from a compact test vessel, dust dispersion is likely to be poor and there is no explosion vent cover.

The mesh (with residual material on the surface) appeared to prevent flame transmission from the lower chamber into the upper chamber; for example Fig. 8 shows flame venting through the 250 mm diameter undersize outlet but did not propagate though the mesh to the inlet in the top cover. The absence of flame ejected through the top chamber suggests that the screen, to some extent, acts as a flame arrester. The sieve was a robust construction and there was no damage or deformation to any part of the sieve body in any of the tests. The sieve unit does not have a pressure rating but it is likely that leakage from various seals would take place before deformation of the vessel.

3.3.3. *Cyclone discussion*

It can be seen from Table 3 that the tests produced P_{red} values lower than those predicted, and that the injected tests were significantly less than the pneumatically conveyed tests. It seems that the pneumatic tests produced conditions more suited to generating higher explosion pressures than the dust injection system. The swirling vortex dust cloud is likely to have been more turbulent than the injected dust cloud.

The difference in the experimental and predicted pressures is due to (a) the open outlet (no vent cover), (b) the inhomogeneous dust distribution in the cyclone, and (c) the geometry of the cyclone, particularly the lower part of the cone, which will tend to promote flame quenching at the cyclone wall.

It is possible that the vortex finder may act as a vent duct and consequently could increase the P_{red}. Recent draft revisions to the standard (prEN14491:2011) gives an informative annex to venting of cyclones and treats the immersion pipe (vortex finder) as a vent duct.

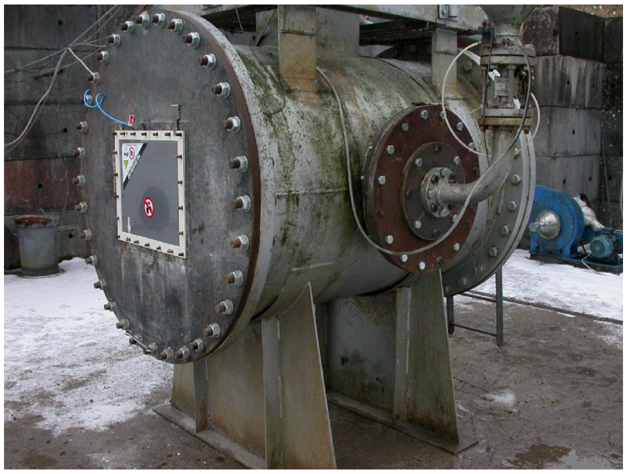

Fig. 11 – 2 m^3 vessel with vent panel.

4. Flameless venting

4.1. *Method*

A flameless venting device providing 0.2 m^2 vent area was tested in conjunction with a 2 m^3 vented test vessel as part of a programme to investigate the performance and limitations of the venting devices. The front face of the test vessel incorporates a vent opening designed to accept the either weak bursting panel or a flameless explosion-venting device of the same vent size. The tested flameless venting device incorporates several dust retention screens.

The explosive dust cloud is produced by injection of a pre-weighed mass of dust into the vessel from an external pressurised dust injection system and ignition is initiated at the centre of the vessel. Pressure transducers are located at the wall of the vessel to record the pressure–time data. Tests were carried out in accordance with the principles of BS EN 14797: 2006.

Fig. 11 shows the vessel with a conventional stainless steel explosion vent panel attached and Fig. 12 shows a flameless venting device attached with the vent panel.

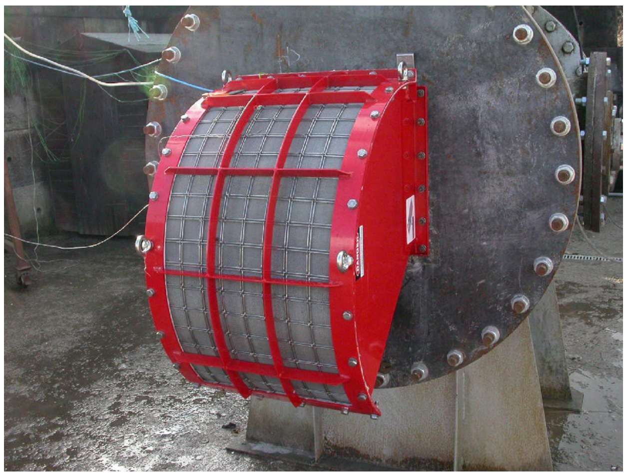

Fig. 12 – 2 m^3 vessel with flameless venting device.

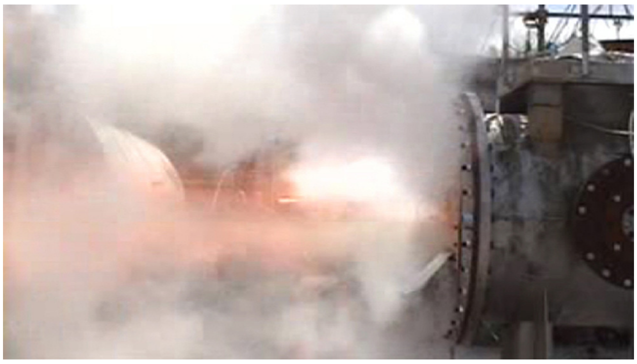

Fig. 13 – Example of a conventionally vented explosion (Test 46).

4.2. *Flameless venting test results*

Tests with cornflour and wheat flour showed that the flame was completely eliminated by the introduction of a flameless venting device with only smoke, dust and water vapour emitted from the device. For example, Figs. 13 and 14 show a visual comparison of a conventionally vented explosion and one where a flameless venting device is installed. Identical test conditions were used: corn flour with a dust concentration of 0.75 kg/m^3, vessel volume 2 m^3 with a vent area of 0.2 m^2 and ignited in the centre of the vessel. The external vented flame from the conventional rupture panel fitted to the vent opening was quite extensive, with several metres of flame.

Using wheat flour (K_{St} 138 bar m s^{-1}) the P_{red} measured in the initial flameless venting tests did not exceed those measured in tests with simple vent panels fitted to the vessel.

However, using corn flour (K_{St} 147 bar m s^{-1}), the P_{red} measured in the initial flameless venting tests had a marked increase compared with those in tests with simple vent panels fitted to the vessel.

4.3. *Discussion*

The flameless venting devices tested to date have demonstrated flame extinguishment in that no external flame has been observed.

The tested flameless venting device incorporates several dust retention screens and it was anticipated that the dust trapped inside the flame-arrester mesh would lead to higher P_{red} in the test vessel when compared with a conventional vent. Therefore, the results with wheat flour where there was a minimal change to the P_{red} were unexpected. By contrast, for cornflour, the tests with the flameless venting device produced considerably higher P_{red} values, indicating a reduced venting efficiency, when compared with conventional venting. Although the K_{St} of the two cereal flours was not significantly different, the two dusts appeared to produce different performances from the flameless venting device.

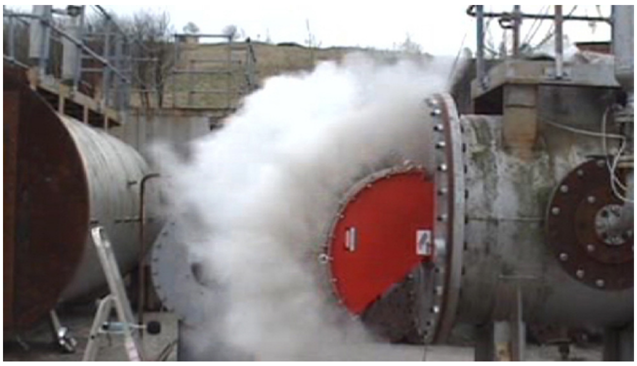

Fig. 14 – Example of a vented explosion with a flameless venting device installed (Test 47).

5. Conclusions

- Tests to date have shown that measured P_{red} values in a 0.5 m^3 compact vented test vessel without vent covers are less than predicted by methods described in BS EN 14491:2006 'Dust explosion venting protective systems'. This is mainly because the standard is based on vent openings fitted with vent covers. Where the exit and outlet openings are used as vents and are not restricted or blocked in any way, the experimental data provides a guide to the expected P_{red}. Where additional venting is required, then the vent design method in BS EN14491:2006 should be used. The P_{red} values measured in real process vessels with volumes <0.5 m^3 (cyclone and a sieve) were also less than the predicted values and again can be explained by differences between the basis of the standard and the vessels' design and operation.
- Flameless venting devices tested to date have demonstrated a high level of flame extinguishment in that no external flame has been observed. These initial tests indicate that the performance of the device appears to be sensitive to dust characteristics other than K_{St}. P_{red} values have been variable and results indicate a reduced venting efficiency when compared with conventional venting.

The experimental work on the small vessels and flameless venting devices is ongoing and final conclusions will be established on completion of the project. Work to be completed includes improving the explosion test procedure to ensure that flameless venting devices are appropriately tested. Additionally, a small dust collector unit is to be tested as part of the small vessel work.

Disclaimer

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References

BS EN 14491, 2006. Dust explosion venting protective systems.
BS EN 14797, 2006. Explosion venting devices.
BS EN 14034-1, 2004. Determination of explosion characteristics of dust clouds—part 1: determination of the maximum explosion pressure ρ_{max} of dust clouds.
BS EN 14034-2, 2006. Determination of explosion characteristics of dust clouds—part 2: determination of the maximum rate of pressure rise (dP/dt)max of dust clouds.
Barton, J., 2002. Dust Explosion Prevention and Protection a Practical Guide. Institution of Chemical Engineers, ISBN 0 85295 410 7.
Going, J.E., Chatrathi, K., 2003. Efficiency of flameless venting devices. Process Saf. Prog. 22 (1), 33–42.

prEN14491, 2011. Dust explosion venting protective systems.

Solids Handling and Processing Association – SHAPA, 2011. Practical Guidance for Suppliers and Operators of Solids Handling Equipment for Potentially Explosive Dusts – Compliance with Legislation Implementing the ATEX Directives. http://www.shapa.co.uk/atex.php (accessed 15.02.11).

Snoeys, J., 2011. Dust Explosion Protection using Flameless Venting. Fike Corporation. http://www.shapa.co.uk/atex.php (accessed 15.02.11).

Stevenson, J.W., 1998. Dust explosion mitigation using Q-Rohr and Exkop. Process Saf. Prog. 17 (3), 184–189.